Dynamic Modelling, Simulation, and Control of an Atmospheric Balloon Platform

Bachelor Thesis

By

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Abstract

The presence of aerostatic balloons has decreased significantly ever since the creation of airplanes. However, even though its role in passenger transportation has evolved into a fundamentally recreational aspect, their endurance and stability make balloons perfect candidates for a wide variety of unmanned missions.

In this document, a numerical simulator for aerostatic balloon will be developed, using high fidelity wind meteorological predictions. Such predictions are provided in probabilistic terms; thus, they introduce uncertainty into the propagation of the system evolution. The simulator will allow for both the most feasible trajectory as well as the dispersion of such nominal trajectory.

The simulator will be validated using flight data provided by the Aerospace Instrumentation Group (CDA-IPN-CCADET-IINGEN-UNAM).

An optimization methodology will be introduced which will allow for the reduction of the balloon's reach and its divergence in non-controlled flights, as well as reducing the cost and endurance in flights where the control system is introduced. This positional control system can be implemented in missions that require precise spatial positioning. In this document, preliminary results for both cases will be introduced.

Dedication and acknowledgements

I would like to be grateful to my tutor Manuel Sanjurjo for his continuous assistance during the development of this thesis as well as for his moral support and continuous encouragement.

This project is also dedicated to anyone that has helped me in the last years and allowed me to be where I stand today. Giving special thanks to my friends here at the university for their sense of humour that pushed me through good and bad moments alike.

Finally I would like to thank my family for giving me the opportunity to study and making a great sacrifice for me to become what I always dreamt of.

Author's declaration

I declare that the work in this dissertation was carried out in accordance with the requirements of the University's Regulations and Code of Practice for Research Degree Programmes and that it has not been submitted for any other academic award. Except where indicated by specific reference in the text, the work is the candidate's own work. Work done in collaboration with, or with the assistance of, others, is indicated as such. Any views expressed in the dissertation are those of the author.

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CHAPTER 1

INTRODUCTION

The increment in balloon applications in the last years makes it necessary for the implementation of a detailed dynamic simulator that would allow for the prediction of trajectories and dynamic behavior of High Altitude Balloons (HAB).

Scientific balloons are the perfect platform for performing both atmospheric and near space experiments due to their intrinsic stability and their floatability capabilities. To do so an in-depth analysis is required of their trajectory to be able to define the conditions the balloon will be exposed in each of the flight stages.

Analysing this information, it is possible to reduce the costs and optimize the trajectory by means of limiting its scatter with respect to the launching area for an easier recovery of the payload or evaluate the optimal launching site to reach a specific altitude and location with the smallest possible time or power consumption.

1.1 Motivation

Presently, different companies are implementing balloons in their operations to perform several tasks that would be either impossible or much more expensive using any other means. The one that stands out is Google's project Loon. Google in the last three years has been studying the control system of balloons to check how accurate their trajectories could be predicted and executed. After designing one of the most complex control systems in balloons nowadays, which will be explained in detailed in the following pages, Google implemented a set of balloons flying in formation equipped with high powered antennas. Their purpose is to provide phone and internet services to different areas in the world that currently lack of high velocity connectivity due to poor satellite coverage.

One of the main points that attract companies is the fact that balloons can perform certain tasks being much cheaper than other alternatives. Basic Meteorological analysis with a weather balloon can be performed for as cheap as 150 euros and only the envelope of the balloon would require to be changed for a subsequent launch since all the equipment can be easily recovered. The affordability of such projects attracts not only universities and scientific groups to perform different experiments using balloons but it is beginning to appeal the broad public and in a way, it is starting to flourish as a trend like aeromodelling is today.

1.1.1 Socioeconomic environment

Although high altitude balloons are mostly used for scientific experiments, they have an important impact in meteorological analysis, allowing meteorological companies to provide tactical data to planes and Air Traffic Controllers merely hours before take-off to ensure aircraft arrive safely to their destination. To acquire this kind of information, weather balloons are used. Weather Balloons carry a radiosonde tethered to the balloon that ascend through the troposphere into the stratosphere and transmit back to a receiving station on the ground obtaining vertical profiles of temperature, humidity, wind speed and its direction, atmospheric pressure and geopotential height. Combining these with satellite information it is possible to reroute aircraft saving fuel and in consequence money for the airline. [18]

The other main application for HABs is near space experiments. With the right type of balloon, it is possible to ascend way over plane flight altitude and perform experiments in space-like conditions but with a much lower investment since the price of lifting a payload with a high-altitude balloon is several orders of magnitude smaller than sending such payload to space with the use of a rocket launcher. Even NASA has shown interest in such endeavour financing several projects involving this kind of technology.

One of the most revolutionary applications comes from planetary exploration, in 1984, the Soviet Union took advantage of the appearance of comet Halley in 1968 to reach Venus, deploying there two balloons, one in each mission to acquire data from Venus, provide interesting information about its atmosphere and soil composition studying then the viability and habitability of such planet.

1.1.2 Regulatory framework

For Europe, the Civil Aviation Authority (CAA) establishes the regulations for unmanned free balloons. The CAA classifies these kind of balloons in the following way[3]:

- **Light:** This kind of balloons carry a payload distributed into one or more packages with a total mass of less than 4 kg or has one of the characteristics of a heavy balloon.
- **Medium:** The total weight of the payload must lay between 4 and 6 kg or has one of the characteristics of a heavy balloon.
- **Heavy:** Any balloon that carries more than 6 kg, any of the individual packages weighs more than 3 kg, a package of 2 kg with an area density of more than 13 g per square centimetre or lastly, uses a rope that requires more than 230 N to separate the payload from the balloon.

From there, the following operating rules must be followed:

1. The balloon must not be operated without authorization from the State where it is launched.
2. With the exception of light balloons used for meteorological purposes, in case of crossing the borderline of the state, the authorization of that state is required.
3. The authorization is required prior launch if there is reasonable expectation.
4. The balloon has to be operated following the conditions specified by the State
5. The balloon must be operated in such a way that the impact of either the envelope or the payload with the surface of the earth does not create a hazard to persons or property.

6. A heavy balloon must be operated in coordination with the ANSPs.

Some limitations and requirements for the equipment are established:

1. A heavy balloon must not be operated under 18000 m in case of low visibility (less than 8km)

2. Medium or Heavy balloons must not fly under 300m over congested areas of any kind.

3. Heavy balloons require two flight termination systems operated independently by telecommand. The envelope must be equipped with radar deflective devices or material so that they can be tracked continuously from a ground-based radar.

4. If the suspension length of the cable from which the payload hangs is larger than 15 m, it cannot be operated at night under 18000 m.

Some notification is required pre flight:

1. Pre-flight notification.

2. Early notification in case of medium or heavy balloon at least seven days prior launch.

3. The notification shall include the following information.

   - Balloon identification (Not required for light balloons)
   - Balloon classification and description
   - SSR code (only for heavy balloons)
   - Operator's name and telephone number
   - Launch site
   - Estimated time of launch
   - Number of balloons to be launched
   - Intended direction of ascent
   - Cruising levels (pressure-altitude)

- Estimated time to pass over the 18000 m altitude as well as its aproximated coordinates.
- Any changes must be notified to the air traffic services at least 6 hours prior launch.

4. In case of a medium or heavy balloon it is required to issue a launch notification with similar information to the Pre-flight notification.

5. In case of cancellation, the air traffic services must be informed.

In Spain, a Pre-flight notification was issued for the experimental launch to be performed in July which was classified as a light balloon. an example of this notification can be seen in appendix A.

High altitude balloons legislation is defined in the USA in depth by:

- The Federal Aviation Administration (FAA) - FAA Part 101 [11]
- The Federal Communications Commission (FCC) - FCC 22.925 [5]

Although it is an unmanned vehicle, according to FAA's Part 107 regarding Small Unmanned Aircraft Systems (UAS) weather balloons do not fall under UAS or drone laws hence they do not require any registration number and have an increased freedom when considering domestic use.

In summary, the applicable rules the HAB must follow are the following:

1. Any cellular phone using GSM network must be turned off or disable such connections as soon as it leaves the ground.

2. Any singular payload must weigh less than 4 pounds and its weight to size ratio must be less than 3 ounces/square inch (total weight of payload divided by its smaller face).

3. Any singular payload must weigh less than 6 pounds.

4. The maximum payload distributed between 2 or more packages carried by the balloon must weigh less than 12 pounds in total.

5. The suspension system of the payload, rope or otherwise must be designed in such a way that it resists at least an impact force of 50 pounds without separating the payload from the balloon.

6. The balloon must be operating ensuring good faith, in no manner that it creates danger for one self or others.

7. No person operating any balloon may allow the dropping of ballast or any other object such that it creates a hazard to other people or their property.

8. No unmanned balloon may be operated with the intention of creating hazard to others.

9. No person operating any unmanned balloon may allow an object to be dropped creating hazard to others.

As long as these regulations are complied, no extra official procedure is required for the launching of a small balloon although it is recommended to issue a NOTAM (Notice to Airmen) by contacting the local ATC 6-24 hours prior to launch specifying intended launch time and date, location, estimated burst altitude, estimated flight duration, estimated location of impact, balloon diameter and size of the payload.

1.2 Goals

In this project, a numerical simulator has been coded to provide pre-tactical trajectory analysis for mission planning based on precise wind predictions. Such simulator will supply trajectory prediction for both non-controlled and controlled balloons allowing for the optimization of their respective trajectories.

In order to check the validity of the simulator, its results will be compared with experimental data provided by the Aerospace Instrumentation Group expecting to find future improvements for the simulator itself as well as checking the validity of the dynamic model.

In summary, the main tasks are:

- Creation of a dynamic numerical model able to define the trajectory of a balloon launched from any location in the world at any given time.
- Implementation of wind forecast data in such simulator to be able to predict trajectories.
- Analyse the uncertainty propagation coming from the wind forecast and the process of the balloon filling that makes it difficult to measure the exact amount of helium introduced thus creating uncertainty in the initial value of the buoyancy force.
- Validation of the model with experimental data.
- Implementation of a control law in such model to analyse control-implemented missions.
- Optimization of the uncontrolled model to reduce the scatter of the balloon from its original take-off point.
- Optimization of the controlled model to reduce the expenses and the cost coming from the control system.

1.3 Background and History

Ever since humankind became sentient, men have dreamt of flying, and even though several machines trying to achieve the flying of birds were designed, it was not until the development of balloons that flying became possible since the floatability of the balloon was much easier to achieve than the lift generation of a wing.

It was then, in 1783 when the Montgolfier brothers' balloon was used for the first manned flight achieving a milestone in history. However, it was not until 1785 when control was implemented and Jean-Pierre Blanchard crossed the English Channel.

Supremacy of balloons remained until aircraft came into play, the first one appearing in 1903 designed and built by the Wright Brothers; they absorbed the market quickly since they were much faster and maneuverable and their application for military purposes was undoubtful. Balloons were a static objective in the air easy to target while planes were constantly changing trajectories.

In 1852 balloons acquired new importance in the form of blimpers (commonly known as zeppelins or airships) thanks to Henri Giffard that built the first engine powered airship. Graf Zeppelin was the most important airship carrier and allowed airships to become competence against ships to cross the Atlantic since at the time the range of airplanes was limited. However, on May 6th, the Hidenburg disaster happened. The German passenger airship LZ 129 Hidenburg caught fire when attempting to dock killing 36 people. The disaster had an immense news coverage around the world and in the end hastened the demise of Zeppelins. With the non-stop advancements in airplane aviation, balloons ended up as a recreational transport only.

Nowadays, besides their recreational purpose, balloons have been dedicated mostly to marketing or unmanned missions for scientific studies or meteorology analysis allowing for the measurement of atmospheric parameters as the balloon lifts into the air. The latest application can be attributed to Google, the company launched a project in the last years called Project Loon. Its purpose is to provide internet coverage via phone reception, setting a set of antennas hanging off balloons which will stay airborne during several months correcting the trajectory constantly thanks to the integrated control system and software. This control system will allow the balloons to never leave the target area and hence provide an uninterrupted service.

1.4 Project Summary and Tools Used

The following list specifies the tools and resources used in this project:

- The software used to define the simulator and perform the optimization has been Matlab.
- The meteorological data was obtained from NOAA for both the nominal trajectory and the ensembles.
- The data provided to check the fidelity of the document was provided by the Aerospace Instrumentation Group(CDA-IPN-CCADET-IINGEN-UNAM).
- An optimization tool provided by Matlab would be use as it best fits .

- The selection of the control system was based on a simplified version of Google's patent for project Loon.

1.5 Time Planning

In this section the time distribution for the tasks developed is explained determining how much time was dedicated for each of the tasks.

- Definition of the scope of the problem as well as the characteristics of each of the tasks to be performed.

- Research period, time dedicated to study about the topic and acquire the necessary information to develop the work proposed.

- Simulator code, write the code applying the dynamic equations to define the trajectory, apply the code taking into account the uncertainty and optimize the function.

- Writing of the thesis using the acquired information and analyse the obtained results.

- Perform the experimental procedure after mounting the circuit and develop the Arduino code.

Dynamic Modelling, Simulation, and Control of an Atmospheric Balloon Platform		
Task	Aproximated dedicated time	Time Period
Problem statement	5 hours	November-December
Documentation	120 hours	December-May
Coding	80 hours	January-June
Writing	100 hours	February-June
Experimental	40 hours (estimated)	June-July

Table 1.1: Time Planning

1.6 Budget

The approximate cost of the project is established in this section, different parameters will be taken into account ranging from the experiment material cost to the salary of an average engineer.

- **Experimental budget**. The experimental launch of the balloon will require a set of components to perform the launch itself as well as the recording and processing of the data acquired during the ascension.

Budget for the experiment	
Arduino UNO R3	30 euros
2 Globos de 600g	70 euros
SIM 900	20 euros
Adafruit GPS	50 euros
Sports Camera	25 euros
Battery module	4 euros
Helium tank	40 euros
MPU 6050	8 euros
Total Cost	247 euros

Table 1.2: Experiment budget

- **Engineer Salary** According to the dedicated time and the minimum salary of a junior engineering established in Article 33 of "XVIII Convenio colectivo nacional de empresas de ingenieria y oficinas de estudios tecnicos", the corresponding salary per hour is 9.75 euros/h. Assuming the estimated time required for the full completion of this document including the experimental procedure, around 345 hours, the total approximated payment for the workforce is 3363.75 euros. [6]

- **Software cost** Since Arduino is an open software, the main program used which results in an important economic cost is Matlab. Right now the Matlab licence for commercial use is 2000 euros in case no extra toolbox is required. For this particular case, the Optimization Toolbox and the global Optimization Toolbox are required adding up to a total price including the main licence of 4150 euros. [16]

- **Coding tool** In order to develop the code, a personal computer was used. Since such computer was already owned, a depreciation system will be added. The original price of the computer was 1200 euros. Such market price will be assumed

Total Budget	
Experimental set-up	247 euros
Salary	3363.75 euros
Matlab	4150 euros
Computer	200 euros
Indirect costs (15%)	1194 euros
Taxes (21%)	1922 euros
Total Cost	11077 euros

Table 1.3: Total Budget

to lose its total value at around six years. By applying a linear depreciation rule, the monthly depreciation is 16.67 euros while fora year which is approximately the time dedicated to the project it will be 200 euros.

1.7 Structure of the Document

The document is organized in the following chapters to ensure a simplified reading:

1. **Balloon Model**. In depth analysis of the equations that define the balloon motion as well as the simplifications applied to limit the calculation time while conserving as much accuracy as possible. In this chapter an explanation of the meteorological data from NOAA can be found as well. Lastly, an analysis of the types of balloons and control systems present right now as well as the reason behind the selected one for the simulator.

2. **State of the art**. Current main uses of balloons and technological advances made in the last years.

3. **Results of the simulation**. Exposition of the specific case to be studied, coordinates and time location, analysis of the results for both nominal and ensembles and finally evaluation of the validity of the simulator.

4. **Optimization**. Establishment of the optimization problem including both non-controlled and controlled cases with the respective selection of the optimized parameters as well as the control variables for each case.

5. **Applicability**. Future and current tasks where balloons could add an edge to improve the way such tasks are performed.

6. **Conclusions and future work**. Summary and conclusions after the project realization, possible improvements and future work.

CHAPTER 2

State of the Art

Currently, several companies are starting to invest in projects regarding high altitude balloons for new applications, the main ones will be explained on the next lines as well as some original ideas proposed after the study of HABs related information prior writing this thesis.

2.1 Project Loon

Around 2011 Google started developing a new project focused on providing internet coverage to different areas in the world by using balloons. The focus of this endeavour is to launch and maintain a fleet of balloons in order to provide both internet and phone coverage as well as providing the means to replace the balloons automatically once their lifespan expires.

The balloons will operate in the stratosphere at altitudes up to 25000m where the wind is heavily stratified in layers and wind speeds are low. Using the layer stratification of the wind, it is possible to define a control system only based on altitude variation that will provide accurate longitudinal and latitudinal variations. Such control system will be explain in depth later on in this document.

The balloon fleet is able to communicate using optical technology such as led and lasers and with ground stations using high frequency radio communications, combining both of methods allows them to fly coordinated and cover the target area more efficiently. [4] [14]

Google intends to substitute fibre-cable ground infrastructure with their system providing a much cheaper internet service. In the end, Google expects to raise up to 10 billion dollars a year coming from project Loon alone and aims to target 4.5 billion people around the globe who have no internet access.

(a) Low Temperature Test Chamber [13]

(b) Test Launch [13]

FIGURE 2.1. Project Loon

2.2 BETTII

BETTII stands for Balloon Experimental Twin Telescope for Infra-red Interferometry. NASA started this project several years ago to provide access to the cosmos similar to that of an orbiting observatory.

Directly quoting from NASA's explanation of the project. "*BETTII is an 8-meter boom interferometer to operate at wavelengths of 30-90 mm on a high-altitude balloon. The long baseline will provide unprecedented angular resolution (~0.5") in this band, and the high atmospheric transmission at balloon altitudes will allow the unique double-Fourier instrument on BETTII to obtain spectral resolution up to* $R \equiv \lambda/D\lambda \sim 100$*. The combination of these capabilities will provide spatially resolved spectroscopy on astrophysically important sources, exploring the physical processes that lurk below the resolution limits of current FIR facilities*" [17].

With this new technology NASA has allowed for a new level of space exploration directly from earth thanks to balloon technology and now supplements data to different research facilities to get a further understanding of the cosmos.

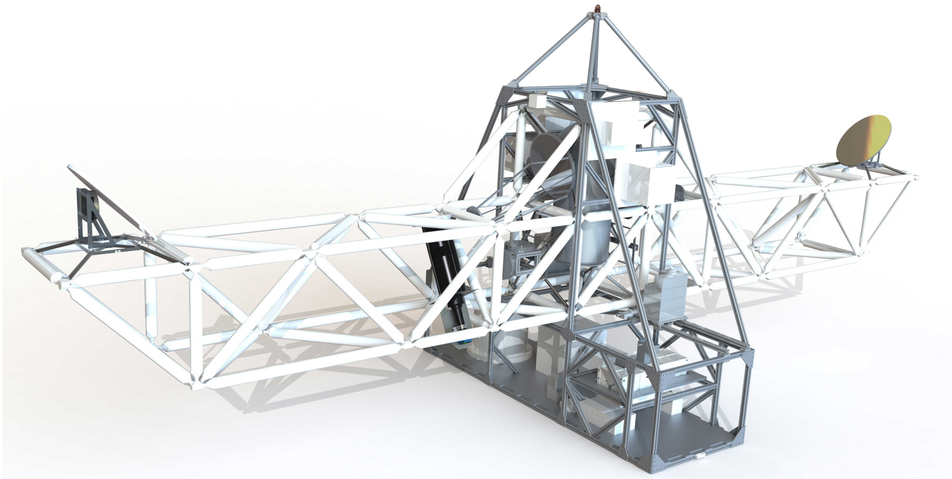


Figure 2.2: BETTII Telescope [17]

2.3 SADM-1

This experiment was performed by a collaboration between the Mexican National Polytechnic Institute and the Aerospace Development Centre. Their main purpose was the launching of a High Altitude Balloon to test a piece of hardware that would eventually be integrated into a low orbit satellite. The experimental module SADM-1 is able to take and process several sources of information to allow for the study of seismic precursors as well as perturbations in the ionosphere. [9]

Such study, will allow for a deeper understanding of the relationship lithosphere-atmosphere by identifying subtle variations in the atmosphere that happen before earthquakes of category seven or larger in the Richter scale.

2.4 Wildfire Detection

One of the future tasks that could be performed by balloons would be high fire-risk areas. according to La Xunta de Galicia, the average cost every hour to extinguish a large fire is around 50000 euros. but it is not only about the economical costs, according to

Greenpeace, forest fires have a large impact over the flora, fauna water and atmosphere quality having everlasting effects over a region. Such effects could be greatly reduced using a better detection system. [7]

Right now, the main detection system used is sight-spotting, which is greatly unreliable, or systems based on visible fire which may not manifest until the fire has already expanded considerably. By using a High Altitude Balloon covering a certain area, using an ultraviolet or infra-red camera it would be possible to control certain areas that are more prone to fires in certain seasons of the year. The system would be able to signal a response team in a short time to extinguish the fire before it even stars spreading.

CHAPTER 3

METHODOLOGY

The whole work load can be mainly divided into two parts, first the modelling of the balloon's dynamics and optimization problem definition and second, the experimental set-up.

3.1 Balloon Model

The first part is the one related with computer coding. The first step was the simplification of the dynamic equations and their implementation into a script coded with Matlab software. The code can be understood as a black-box that takes the launching coordinates of the balloon, and its initial conditions, mass of payload and of lifting gas and calculates the trajectory it will follow until the point where the integration time concludes or until the balloon bursts and falls to the ground. To calculate the aerodynamic forces the balloon is under, the software imports data from the National Oceanic Aviation Administration NOAA and provides accurate predictions for the velocity, and temperature in each of the points of the balloon's trajectory.

The code allows as well to introduce uncertainty into the system by means of importing a different file from NOAA's database. It includes a total of 21 feasible trajectories with small modifications between them in such way that they provide a viable way to graphically show the uncertainty of the forecast. The same procedure is applied to the controlled problem, another code was written with similar characteristics to the previous one but when the balloon reaches its floatability altitude, it is possible to control it with a set of valves and compressors that introduce or drain air from the balloon's envelope. Using this method, the balloon changes volume and consequently, altitude. Thus, due to the stratified layers of the stratosphere and their variability in wind direction it is possible to keep the balloon hovering around a constrained area.

Finally, it was possible to optimize both cases using Matlab's Optimization Toolbox. The main parameter to be optimized in the uncontrolled trajectory would be the scatter distance of the payload, the closer the balloon bursts from the launching point, the shorter will be the travelled distance for the recovery of the payload. And for the controlled problem, the main optimization parameter would be the power of the compressors driving air into the envelope.

3.2 Experimental Balloon Launch

In order to validate the model, an experiment will be performed consisting on building and launching a balloon carrying sensors, analyse the whole trajectory and compare it with the one predicted by the simulator. The balloon will be launched from a selected position ensuring with the simulator that the payload will fall into a safe area since it has no means of slowing down once the balloon bursts, hence it will free fall. Combining the safe area study with the an air route analysis the optimal location will be selected to avoid any kind of interference with airplanes.

The balloon will ascend and record the whole ascension with a camera and it will record the GPS position and a gyroscope and an accelerometer will record angles and accelerations. Afterwards thanks to a transmitter incorporated in the payload, the system will transmit its landing position so that the payload can be recovered.

The system set-up can be divided in the following parts:

- The balloon envelope, a latex spherical film that will provide the lifting force when filled.
- The lifting gas will be helium due to its price and low density.
- The whole process will be recorded with a high definition camera.

- An Arduino UNO module is implemented to handle the acquisition of data.
- An MPU 6050 integrated circuit includes both the accelerometer and the gyroscope.
- All the data will be safely stored into a microSD card.
- A GPS module to provide the coordinates at each time.
- A telephone SIM card module to provide the landing position.
- A styrofoam protection to ensure all components' safe landing and keep a high enough temperature for the components to work at high altitudes.

3.3 Dynamic Equations

Considering the coordinate system shown in figure 3.1 which depicts an Earth reference frame whose Z axis points upwards in the positive direction of the altitude, the X axis points to the geographical true north and the Y axis completes the right hand system. [21] [15]

From this system the balloon position can be defined and will be denoted as (x_b, y_b, z_b) the velocity vector of the balloon represented with V_b having components (v_{bx}, v_{by}, v_{bz}) and the wind velocity whose components will be parallel to each of the earth axis $(v_{w_{lon}}, v_{w_{lat}}, v_{w_z})$ defining v_{lon} as the longitudinal component and v_{lat} as the latitudinal one of the velocity while the z component will coincide with the balloon's one.

Once the coordinate system is defined, it is possible to stablish the the forces acting on the balloon. The wind exerts two main forces on the balloon, those being the drag force and the equivalent to a lift force that will be called side force from now on. It will appear laterally in balloons and will be caused by the deformation these balloons experience due to gusts or defects in the materials. These factors generate an asymmetry in the velocity profile leading to the appearance of a pressure difference which in the end will result into a force. The drag force denoted by C_D will always act parallel to the relative wind vector and the side force denoted by C_D will always act perpendicular to the relative wind velocity.

$$F_D = \frac{1}{2}\rho_a |v_w - v_b|^2 C_D A_b \tag{3.1}$$

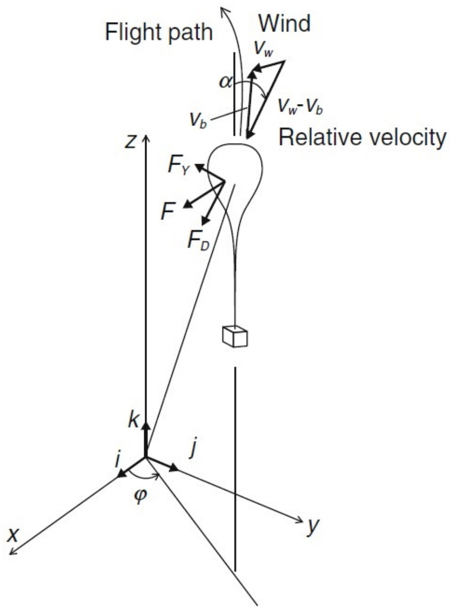


Figure 3.1: Reference Frame [21]

$$F_Y = \frac{1}{2}\rho_a \left|v_w - v_b\right|^2 C_Y A_b \tag{3.2}$$

A_b is the maximum cross-sectional area perpendicular to the balloon's axis and in order to obtain it, it is necessary to know the shape of the balloon. Then, ρ_a will be the air density which will change as a function of the altitude but instead of using a standard ISA model and having access to precise meteorological data, the density will be obtained as a function of the data of pressure and temperature provided by NOAA. Thus using the formula

$$\rho_a = \frac{P_a m_m}{T_a R_u} \tag{3.3}$$

Denoting m_m as the molecular mass of the air which will be assumed as constant and of value $m_m = 28.97$ [g/mol] while R_u is the universal mass constant and of value $R_u = 8.314$ [J mol^{-1}K^{-1}].

The force coefficients C_D and C_Y can have a wide spectrum of values depending on the shape of the balloon. For C_D the values ranges from 0.2 to 0.5 while for C_Y the variation is much larger starting from almost 0 with spherical balloons to values similar to the drag coefficient for more anisotropic shapes.

For the simulator, since the balloon will be assumed spherical and the only change in volume will be produced isotropically the drag coefficient will be $C_D = 0.5$ and the side force coefficient will be then assumed to be zero $C_Y = 0$.

From here it is important to define the angles relating the velocity of the balloon and the absolute velocity as they will be used to decompose the force into the axes of the coordinate system used in this document.

The first angle to be considered is the theoretical angle of attack α, this angle is the one between the balloon's relative velocity $(v_b - v_w)$ and the vertical axis z.

The second one will be called φ and it is the angle between the x axis and the vector obtained by projecting the relative velocity vector $(v_b - v_w)$ over the xy plane.

From there it is possible to fully defined the forces in the three directions of the Earth fixed reference frame explained at the beginning of this section. Obtaining the following equations.

$$F_x = (F_D sin\alpha + F_Y cos\alpha)cos\varphi \tag{3.4}$$

$$F_y = (F_D sin\alpha + F_Y cos\alpha)sin\varphi \tag{3.5}$$

$$F_z = -F_D cos\alpha + F_Y sin\alpha \tag{3.6}$$

Now the aerodynamic equations have been defined, the other set of forces that define the motion must be specified, those being the weight, and the buoyancy force.

The mass is divided in the different parts composing the balloon, including the balloon's envelope m_b, the payload m_p which will include all telemetry and electronics as well as any means of environmental protection those elements require for high altitude hazards and the balloon's ballast m_c. The addition of the aforementioned masses compose the gross system mass also known as balloon system mass m_G thus:

$$m_G = m_b + m_p + m_c \tag{3.7}$$

The total mass of the balloon m_t can be found adding the mass of the lifting gas m_g to the gross system mass:

$$m_t = m_G + m_g \tag{3.8}$$

Although the total mass of the balloon is defined, in order to apply the equations, there is another parameter that needs to be taken into account and this is the virtual mass which refers to the mass of air dragged along with the balloon.

$$m_{virtual} = C_m \rho_a V_b \tag{3.9}$$

Being C_m the virtual mass coefficient depends on the direction of the balloon's acceleration ranging from 0.4 at launch to 0.65 when the balloon achieves its full expansion. However, for a spherical balloon the coefficient will be 0.5 and this is the value implemented in the simulator.

The final mass that will be used in Newton's second law will be m_v found out by adding the virtual mass to the total mass:

$$m_v = m_t + m_{virtual} \tag{3.10}$$

Now, the buoyancy force must be taken into account. Buoyancy is an upwards force applied by a fluid on an object immersed in such fluid that opposes the weight of the object. It is caused by the difference in pressure between the top and bottom surfaces of the immersed object, this pressure difference causes a net upwards force that is defined as buoyancy. Its magnitude is defined by the displaced volume of water the object occupies:

$$F_b = \rho_a V_b g \tag{3.11}$$

From here on, the process will be applying Newton's second law in the three main directions previously defined.

$$\sum F_i = m a_i \tag{3.12}$$

Being i each of the three directions leading to the following equations

$$m_v \frac{d^2 x_b}{dt^2} = F_x \tag{3.13}$$

$$m_v \frac{d^2 y_b}{dt^2} = F_y \tag{3.14}$$

$$m_v \frac{d^2 z_b}{dt^2} = (\rho_a V_b - m_t) g + F_z \tag{3.15}$$

Assuming the lifting gas is an ideal gas the volume of the balloon changes with altitude in the following way:

$$V_b = \frac{m_g R_u T_g}{m_{m_g} P_g} \tag{3.16}$$

being the conditions the ones inside the balloon, the pressure will be the one defined at sea level once filling the balloon, the temperature as a first approximation can be assumed the one outside the balloon, simulating the heat flow into the balloon is one of the proposed future works than could improve the simulator.

From this equations it is possible to identify the parameters that can be modified to fully define the trajectory for non-controlled balloons. Starting with the launching location which will define the wind profile the balloon may encounter based on NOAA forecasts. Then the initial mass, assuming the envelope of the balloon is defined as well as the payload, only the amount of lifting gas introduced in the balloon will be modified. These two parameters will be the ones that can be optimized to reduce the scatter of the balloon from its original location in non-controlled flights when defining for example the trajectory of a sounding balloon.

For the control system, one of Google project's will be used, a high pressure gas chamber to inject or suck air from the balloon to change its effective volume changing then altitude that will be explained at the end of this chapter.

To model such system, a couple of valves will be established controlling the inflow and outflow of gas as required to change the altitude, the evolution of gas in the balloon will be then:

$$\frac{dm_g}{dt} = \rho_g(e_1 - e_2) \tag{3.17}$$

where the valves will behave in the following way:

$$e_1 = c_1 A_1 \sqrt{\frac{2\Delta P_1}{\rho_g}} \tag{3.18}$$

$$e_2 = c_2 A_2 \sqrt{\frac{2\Delta P_2}{\rho_g}} \tag{3.19}$$

3.4 NOAA Data

The National Oceanic and Atmospheric Administration (NOAA) formerly the National Climatic Data Center (NCDC) is an American scientific company focused on weather analysis, forecasting and conditions of both the oceans and atmosphere.

The agency delivers and distributes all the information they manage to any company interested in their services. From all services provided by NOAA the ones that were used in this study were the Global Forecast System (GFS) and the Global Ensemble Forecast System (GEFS).

The GFS is a weather forecast method produced by the National Centers for Environmental Prediction (NCEP). Data form GFS is distributed in a series of 120 variables in a three-dimensional spatial mesh around the globe achieving a resolution of 28 kilometers between grid points in the longitude-latitude plane. Meanwhile, 129 files are issued every day with a three-hour difference between them with a maximum prediction of 384 hours into the future.

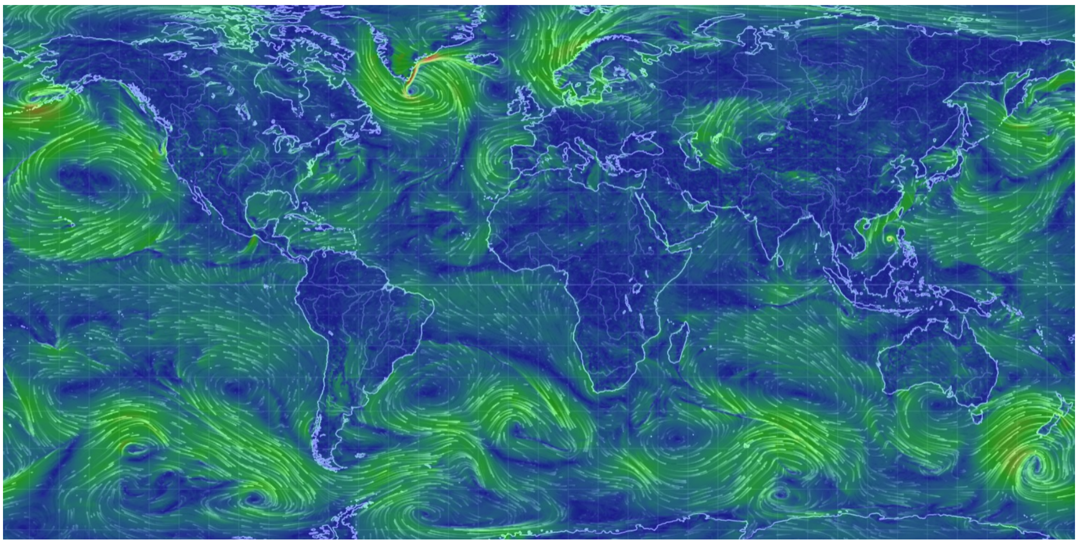


Figure 3.2: Wind on Stratosphere [10]

Despite the fact that using a 0-hour prediction would be the most accurate one, the ones belonging to the days of the experiment are not in the database hence the ones to be used will be from eleven days prior launch since there was a gap in the forecasts in that time period. Although these variables provide useful information that could be applied in the calculation of the trajectory, only a set of them will be used in the reduced model applied in the simulator. The variables required are the temperature, pressure and the three-dimensional velocity.

The GEFS is a weather forecast model made up of 21 separate forecasts or ensemble members. The National Centers for Environmental Prediction (NCEP) address the nature of uncertainty in weather observations, which is used to initialize weather forecasts models.

The GEFS attempts to quantify the amount of uncertainty in a forecast by generating an ensemble of multiple forecasts, each minute different or perturbed, from the original observations. The grid in this case presents twice the distance between grid points as well as twice the time between predictions.

3.5 Balloon Classification

3.5.1 Balloon shape

The first parameter a balloon can be classified by is using its shape, that shape will end up defining the behaviour as well as the force distribution and tensile strength on the film.

Spherical Balloons Neglecting the buoyant force and weight effect on the membrane, the spherical shape leads to a uniform distribution of tension over the entire surface of the balloon.

Although it may seem as the most optimal shape for a pressurized balloon, it presents two main flaws, the first one being the fact that the payload suspension from the balloon will result into a high localized stress that will end up breaking the envelope or require a reinforcing curtain that will translate into un unnecessary increment of the weight. The second one is that while on the ground and in the first ascension period, the balloon will not be completely expanded, leading to a non-uniform tension distribution thus limiting the use of spherical balloons to small balloons with light payload.

This shape will be the one applied for the model since change of shape and membrane tension were not considered in the model due to its little impact on the trajectory.

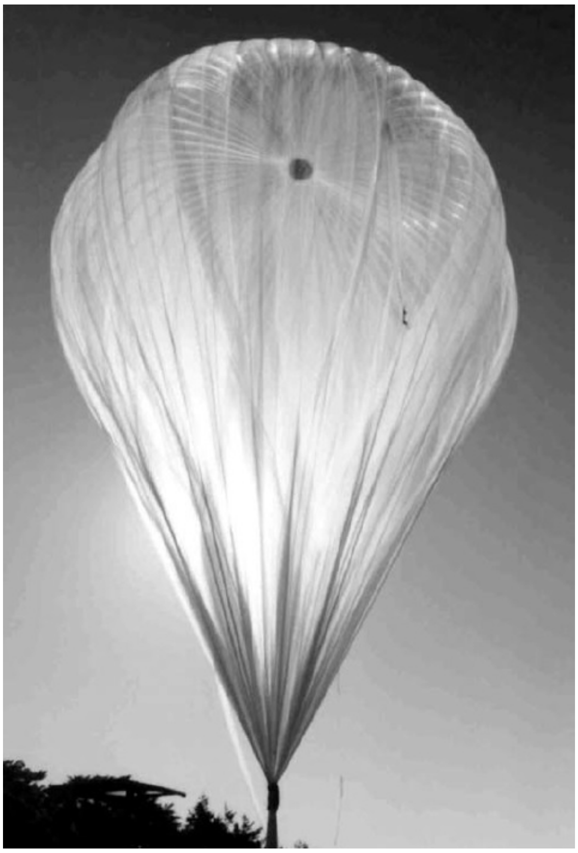
Cylindrical Balloons A cylindrical balloon membrane is defined as a central elongated part while the top and bottom ends are closed off in some form. Its main advantage is the high-pressure resistance. However, its volume to surface ratio worsens. Its main applicability comes in the form of planetary exploration of high density atmosphere planets such as Venus where the buoyancy force is larger.

Tetrahedral Balloons Shaped in the form of a regular tetrahedron, it lacks rotational symmetry and although it may appear not to be a common shape for a balloon, it strongly resembles natural shape balloons which will be discussed in depth later. This kind of balloons present the benefit that it can be easily manufactured.

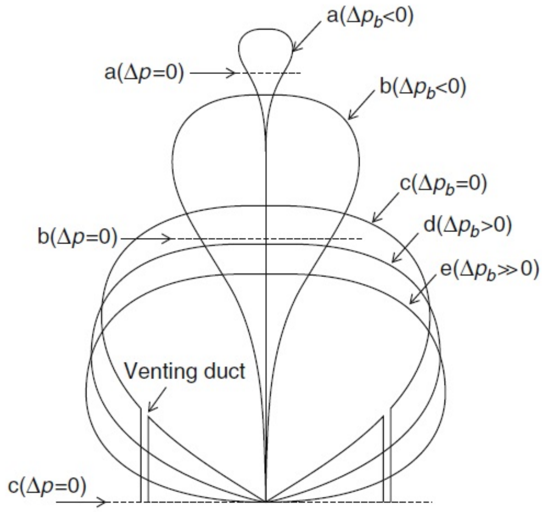
Natural shape Balloons All the aforementioned shapes undergo a strong shape evolution from take-off until the pressure inside the envelope balances with the one outside through the full expansion of the balloon, thus the existence of natural shape balloons was a milestone in balloon design that allowed for a more in depth analysis of their in-flight mechanics since the shape evolution with altitude can be accurately defined. The natural shape balloon is defined as a rotationally symmetrical body made of film. The most accurate explanation will be as an inverted cone topped by a dome. This shape increases the film resistance to pressure allowing to increase the initial gas mass as well as increase the weight of the suspended payload.

3.5.2 Balloon Pressure

Although the balloon shape is a considerable parameter, the study of its pressure evolution with altitude is the one that has the most effect on the trajectory. The main two discernible categories are super-pressure balloons and zero-pressure balloons.



(a) Example natural shape balloon



(b) Shape evolution with altitude

FIGURE 3.3. Natural Shape Balloon

Super Pressure Balloons Super-pressure balloons refer to the standard closed envelope balloon where there is no gas flow between the inside and outside of the balloon. This kind of balloons require a stronger film material since as height increases so does the pressure difference between the balloon and the exterior.

Even though these balloons have a more limited altitude and are much harder to be implemented with a control system, they are optimal for missions where the balloon reaches an altitude where the pressure difference is large enough to break the envelope and hence the balloon bursts and the payload falls into the ground. For the sake of simplifying the equations and matching the experiment performed by the Aerospace Instrumentation Group this type of balloon will be the one selected for the simulator.

Zero Pressure Balloons Zero-pressure balloons are the second balloon category when classifying pressure-wise. This kind of balloon has a venting valve that allows for an automatic regulation of pressure as the altitude increases by venting gas form the inside keeping at all time the pressure at the outside and inside balanced reducing then dramatically the tension the film experiments. Using this type of balloons allow for longer missions and synergizes better with any kind of control system.

3.6 Control system

With the intention of tactically controlling the balloon, a control system needs to be implemented. Although it may seem that a three-dimensional control is required, due to the strong wind speed stratification in the different layers of the stratosphere, it is safe to assume that for most missions, the only requirement is a precise control of the altitude combined with the wind information. The most simple control system is a combination of a venting valve to reduce the balloon pressure and effectively reduce altitude and a ballast dropping system to increase it. [12]

Designing a good control system is still an ongoing problem that companies and developers ar still facing since the unpredictability of the wind must be considered constantly. Meanwhile, the main system for increasing altitude is the dropping of ballast which is a limited resource in the balloon and consequently will be the limiting factor for the mission length.

Google in the last years has been working on a project to implement a series of antennas hanging from balloons which will fly in formation to provide phone and internet service to a certain area and to do so, they designed a complex system that will be explained in the following lines.

3.6.1 Venting valve

The venting valve ensures the pressure inside the balloon is never large enough that the pressure difference with the outside brakes the film. It also allows the reduction of altitude by changing the effective volume of the balloon. When designing, or choosing the valve, the following things must be considered:

- Minimize the escape of the inner gas
- Limit power consumption
- Maximize flow rate
- Minimize weight

3.6.2 Ballast system

Designing the ballast system for manned hot air balloons is simple since once the desired altitude is obtained, it is kept until landing. Thus, not that much precision control is required so discrete masses are enough. The problem increases in complexity when a continued altitude variation is required and a way must be found to turn the original discrete ballast system into a continuous one.

The easiest solution would be instead of dropping a solid ballast, using a liquid one. Having on the balloon a container with a valve controlling the outflow of the liquid would allow for a precise altitude control. Since the temperature at high altitudes decreases drastically, a low freezing point would be required hence one of the possibilities would be the use of ethanol. [12]

Other of the options related with the use of solid ballast would be dropping the batteries that feed the control systems and any electronics the balloon carries. For long term missions that would be a feasible way of not carrying unnecessary weight but its applicability would be restricted by the recovery of such batteries since they are damaging to the environment so a technology evolution in degradable batteries would be required to make this strategy feasible that right now will be left as only a theoretical project.

3.6.3 Project Loon

The final control system to mention is the one incorporated in Google's project Loon which is much more complex than any control system previously introduced in the past. The system is constituted of a variable volume envelope and an elastic membrane that allows for a change of volume without a drastic change in shape. It will behave as a zero pressure balloon with some modifications after reaching the floatability altitude. [8]

The altitude control is performed with a revolutionary system composed of a high-pressure gas chamber. To increase the altitude, high pressure gas is pumped into the balloon's envelope. Meanwhile to reduce the altitude the opposite flow must occur and gas is sucked out of the envelope into the chamber.

The second system os made out of a fuel cell that generates hydrogen and pumps it into the balloon to increase altitude and sucks the hydrogen to react with oxygen and produce both power and water.

The third part of the control system is as simple as painting half of the balloon black, by controlling the part of the balloon that faces the sun, the absorbed radiation will increase the temperature inside the balloon and thus increase the altitude.

CHAPTER 4

RESULTS

4.1 Altitude evolution

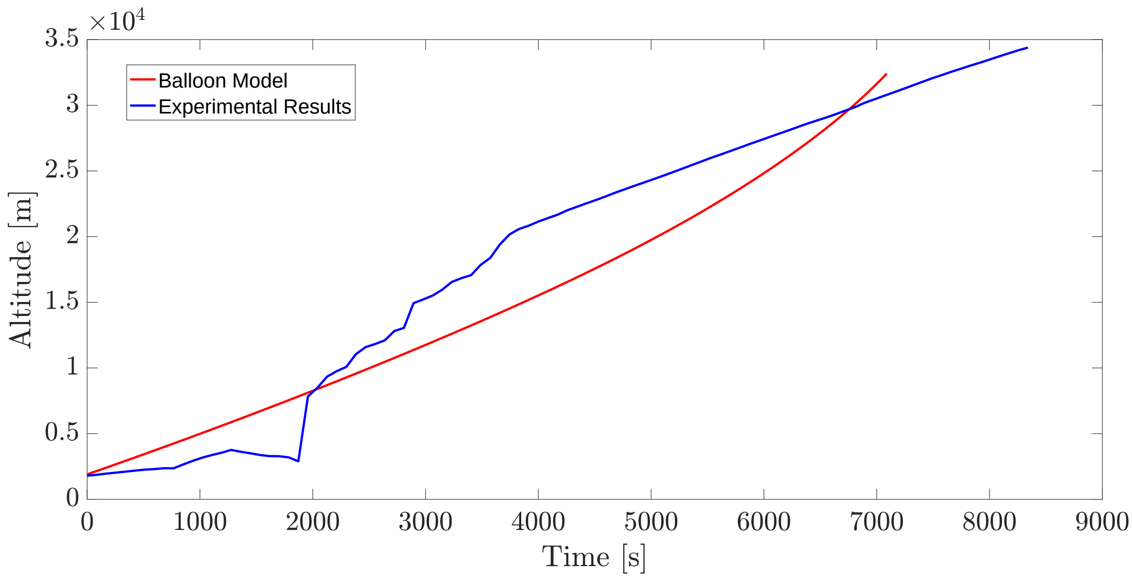


Figure 4.1: Altitude vs Time

In figure 4.1 the time evolution of the altitude is shown. The altitude in the simulator experiments an almost exponential profile due to the assumptions made that the temperature inside the balloon is the same as the external one and the volume expands in a constant manner following the ideal gas law.

The profile of the experimental data differs from the results of the simulator due to several reasons. The first large variation of the altitude has the shape of a sudden peak that alters the expected evolution. These irregularities appear for a while a little longer. The reason behind this issue is that the GPS malfunctioned in several points until the balloon reached around 4000 m.

From there the evolution is still uneven, the presence of defects and irregularities in the material of the balloon makes for an anisotropic expansion of the envelope hence the altitude evolution distances from the one provided by the simulator. Once the balloon fully expands, it is possible to appreciate that the curve becomes a straight line up until the burst of the balloon.

The aforementioned temperature assumption leads to a lower temperature inside the balloon compared with the one present in the experiment. The under-expansion of the modelled balloon with respect to the experimental one explains why the experimental balloon reaches a higher altitude in a shorter time.

It can be appreciated that the modelled balloon does not reach the same altitude as the real one, this is due to the provided wind data which are limited to a pressure level of 1000 Pa, around 31000 m.

It is important to note here that the altitude is completely independent on the wind. NOAA does not provide any kind of information about the vertical velocity, hence turning the altitude into an uncoupled equation from the horizontal trajectory. In conclusion wind uncertainty will play no role on the altitude as it will be shown in the next sections.

4.2 Horizontal projection of the trajectory

In 4.2 the projection of the trajectory of the experimental results does not resemble at all the one of the simulator. Although it may seem odd to add such results, it does make sense as it proves the uncertainty of wind forecasting.

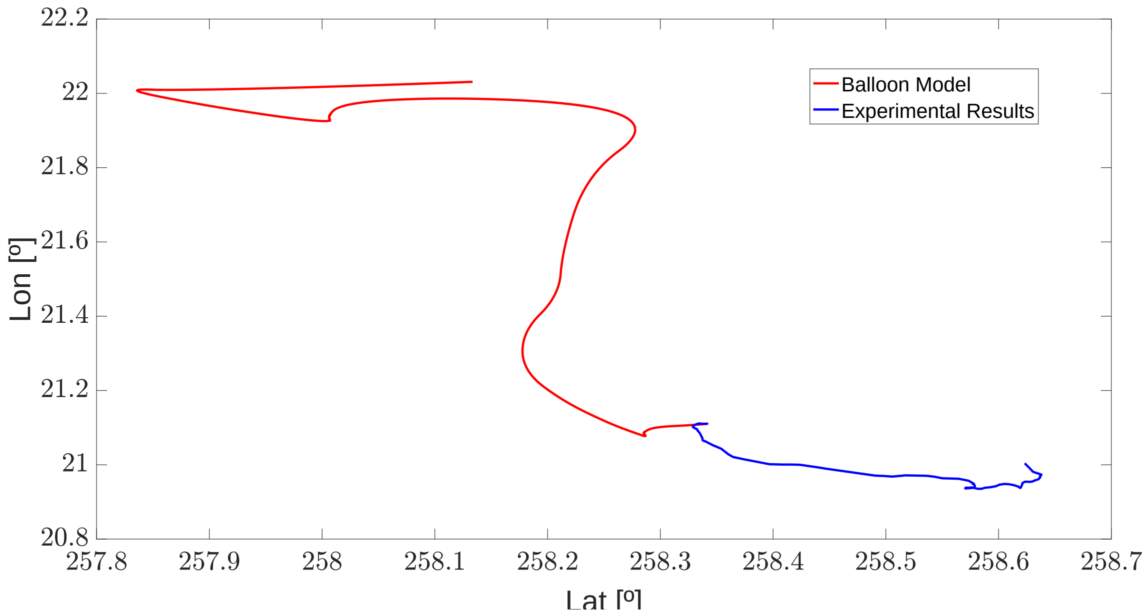


Figure 4.2: Projection over horizontal plane of the trajectory

When trying to get wind data from NOAA to introduce in the simulator and validate the model, there was a problem. The day of the experiment there were no forecast data. The original idea was to take the forecast issued on the day of the experiment at midnight, hence obtaining the least uncertainty. But, as it turned out, no forecast data was issued, neither that day nor in any of the previous 10 days, making the most accurate forecast the one issued 11 days prior launch.

By taking a look at 4.2 the huge effect of such uncertainty can be appreciated, making the validation of the simulator impossible.

4.3 Uncertainty from wind

In order to fully comprehend the effect of the uncertainty on the system, figure 4.3 shows the ensemble solution. The ensembles as aforementioned are different predictions that have small differences between their launch parameters to display a representation of the uncertainty.

In this case, the forecast taken was issued at 00:00 AM the day when the wind data was taken. The simulation starts at 00:00 that same day and ends two hours later at 02:00

AM. Only in the two hours since issuing the forecast the system gives an uncertainty of around 10 Km in each of the directions (being x the longitudinal one and y the latitudinal one).

When increasing the time between the forecast issue and the theoretical balloon launch, the ensembles scatter much more into space. Thus confirming the previous assertion about the importance of uncertainty in weather forecast and proves that in order to obtain better results, the forecast to use should be as recent as possible.

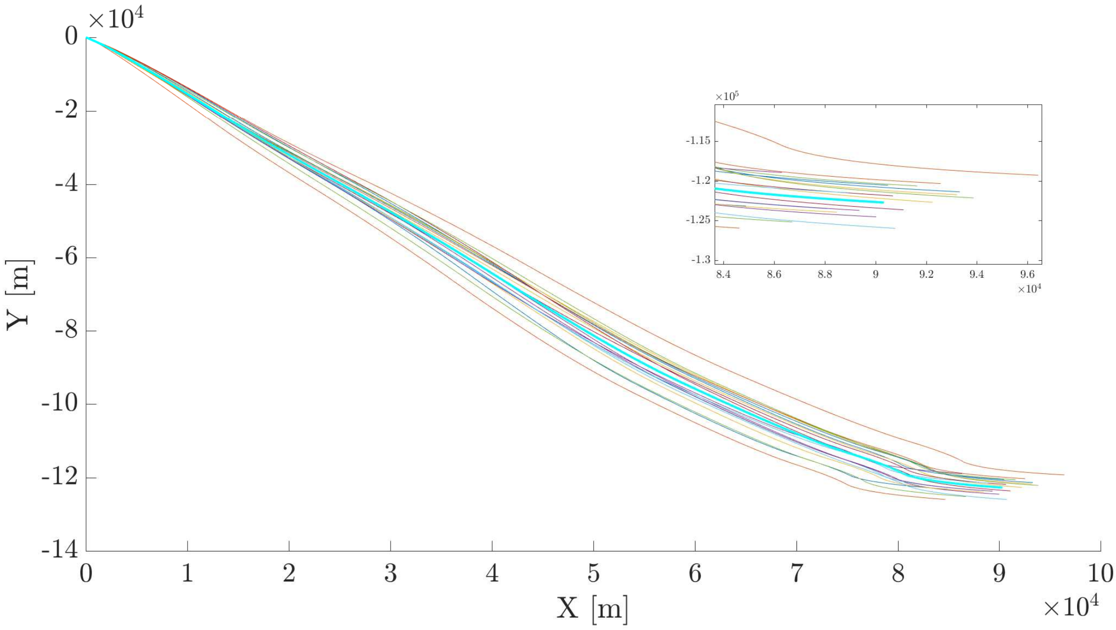


Figure 4.3: Projection over horizontal plane of the trajectory, ensembles

4.4 Uncertainty from filling

Balloon filling is a complex process to perform accurately. The exact amount of helium that goes into the balloon cannot be fully controlled since most helium providers sell helium into tanks without providing accurate information about the pressure and only about the tank's volume.

Also, the measurement of the balloon's volume due to possible anisotropies and defects in the envelope carry some uncertainty as well. So in order to check how the altitude changes with the amount of helium, different missions were simulated only changing the mass of helium inside the envelope giving the results in figure 4.4.

There are two parameters that define the acceleration of the balloon that vary when changing the amount of helium, those being the cross-sectional area and the volume of the balloon, that affect respectively the Drag and the Buoyancy .Since the main effect of changing the amount of helium is the change in the balloon's initial radius, the buoyancy increases more than the drag, thus a balloon with a larger initial radius reaches the maximum altitude faster than the other two cases.

With respect to the projection on the horizontal plane, the larger radius makes the balloon accelerate faster since the lateral drag force is proportional to the square of the radius. Every time the balloon changes directions, the turning radius of the balloon will be smaller the lower the quantity of helium.

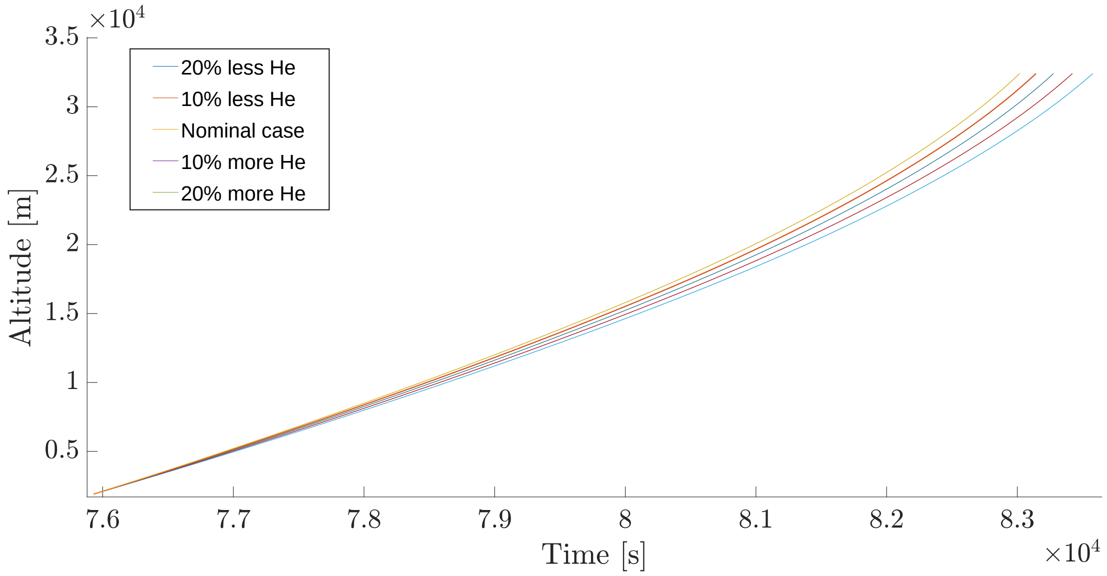


Figure 4.4: Balloon Filling Uncertainty

4.5 Optimizer

Once the simulator is defined, and the dependence of the parameters have been shown, it is possible to create an optimizer for the trajectory.

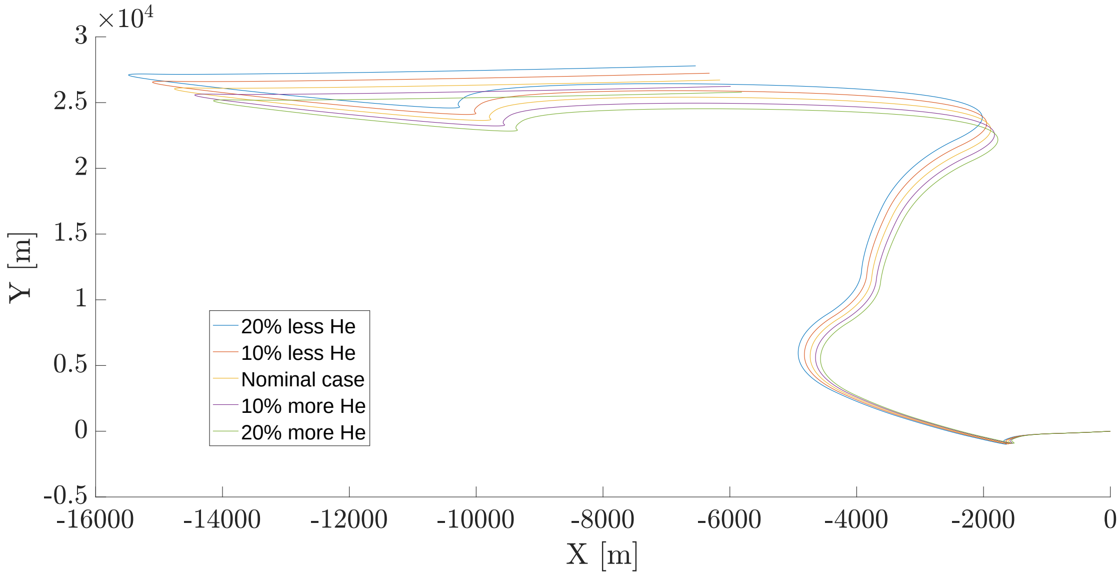


Figure 4.5: Balloon Filling Uncertainty Projection

The objective of the uncontrolled balloon is to ascend, acquire some data and then fall onto the ground. The only problem is the area where the balloon falls. The balloon may cause hazards if it falls onto a car or a person and the electronics may not survive if it falls into a river or lake. That is when the optimizer comes in handy. With the optimizer it is possible to select the landing area, of about 10 Km of radius (distance obtained in the ensemble analysis as the scatter for real time forecasting) and through the optimizer the best launch point will be obtained.

The optimizer accepts as inputs the centre of the landing area, the characteristics of the balloon and your current position and gives as an output the best launching point so that the balloon lands in the selected safe area.

The results of the simulator using a trial value can be seen in 4.6 where the trajectory from the original point is given as well as the optimal trajectory with the landing area. Results are given from the original intended location launch.

The simulator is written in a way that it can be easily modified in case other conditions were wanted to be achieved. Some examples are: reducing the range of the balloon to minimize the distance required to recover the payload, select an area to overfly at a selected point in time or even change the control variables of the optimizer to expand the number of applications.

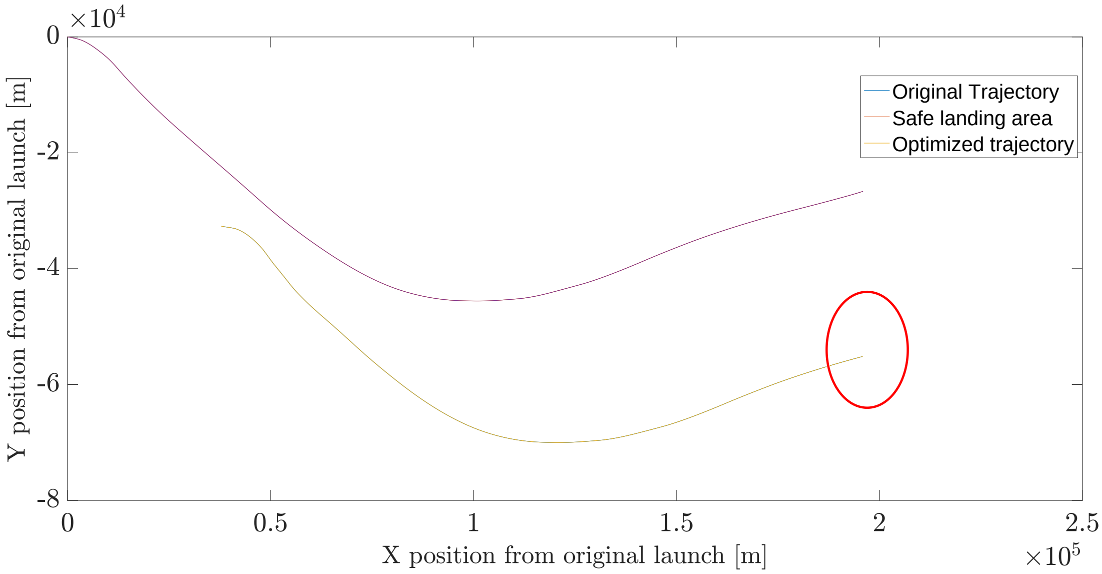


Figure 4.6: Trajectory Optimization

Chapter 5

Experimental Procedure

5.1 Experiment Layout

The mission intended to be performed on the 6th of July 2017 consists on launching a balloon carrying a set of instrumental sensors to validate the simulator this thesis is based on.

The idea is after selecting a safe landing location for the payload, decide using the simulator the best place to launch it and contrast such information with the air routes to check for possible collisions with aircraft.

Once the place selection is ensured, the day of the experiment, proceed to the launching location and launch the balloon so that it travels to the stratosphere where it will burst and let the payload fall to the ground where it will be recovered.

5.2 Experimental Set-up

The specifics of the experimental set-up will be explained in detail in this section.

5.2.1 Balloon's Envelope

The first and most important part of the experiment is the balloon's envelope. It will be the one providing the force that will allow the system to perform its journey to the stratosphere. The selection of the balloon's envelope was made taking into account two main factors, one of them being the reachable altitude and the other one being the cost.

The maximum altitude a balloon can reach is dependant on the envelope's material and its original volume when the balloon has not yet fully expanded. The balloon can only expand to a certain limit due to its elastic capabilities and the one that presented the best resistance to price ratio was latex.

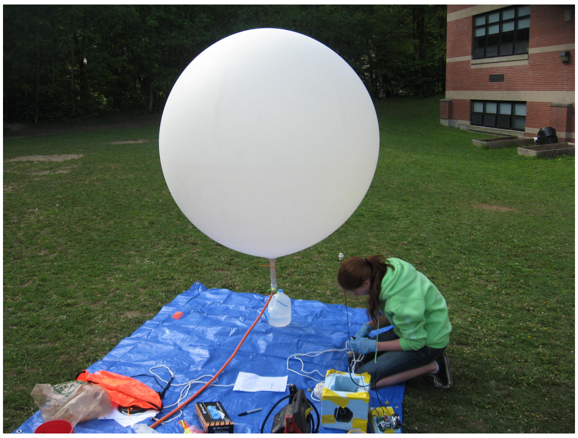
Once the material was selected, the decision was which among the different balloons in offer was the better choice. Available to the broad public most of the balloons sold by different companies are spherical balloons so the shape was not an issue since there was no choice. The real decission was the size of the balloon. Such is provided in the form of the weight.

According to the data the manufacturers provided and the kind of mission intended, the final option was acquiring a spherical latex balloon of 600 grams, able to carry around 300 grams of payload (enough for the electronics) and able to reach 30000 meters, which is the maximum altitude NOAA's data reaches so in order to validate the model, the 600g balloon was the best choice.

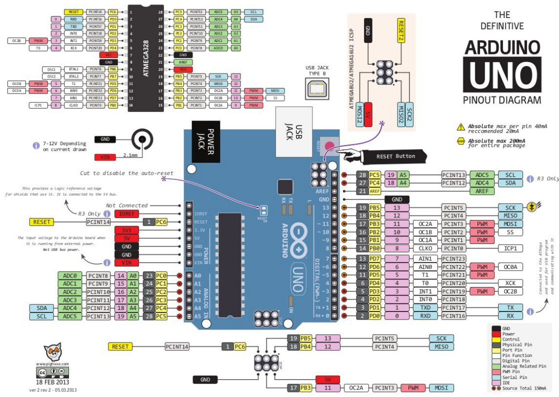
5.2.2 Data Processing Unit

In order to process and store the data acquired by the different sensors, it is necessary to provide a processing unit. Although a wide variety of processing units exist, the final choice was made based on the simplicity of the coding language and the price. The chosen unit was an Arduino UNO R3 because of its lower price and the fact that for the tasks to be performed, a better model was not necessary.

Arduino is an open source hardware and software. Their boards are able to receive and process certain inputs and turn them into outputs. In the particular case of the electronics implemented in the balloon, the inputs will be the acceleration and changes in position of the payload as well as the GPS position. As output, the system will be able to export all the acquired data to a microSD card and send the location via SMS. Figure 5.1.



(a) Amateur Sounding Balloon Experiment [19]



(b) Arduino Uno Schematics [2]

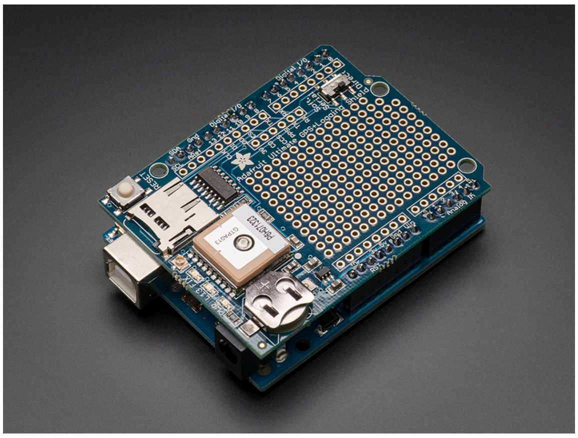
FIGURE 5.1. Experimental Set-up

5.2.3 GPS Unit

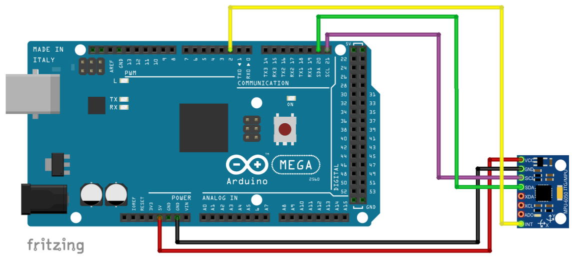
Thanks to Arduino being compatible with almost any extra modules, the selection of GPS module was easy. As barely any module with an integrated GPS was fit for the job, finally one with an integrated memory card slot was selected so that buying such piece later on was not necessary. The module registers the position every second and stores it into the integrated microSD card slot. The name of the unit is the Adafruit GPS Logger Shield. Figure 5.2.

5.2.4 Gyroscope and Accelerometer

Although sold separately, the final decision was to acquire a system integrating both sensors and after checking prices, an affordable option was acquired, the MPU-G6050. Data extracted from this unit will be stored along with the GPS position in the memory card integrated in the GPS. Figure 5.2.



(a) GPS Adafruit



(b) MPU-6050

FIGURE 5.2. Telemetry and sensors

5.2.5 GSM Module

In order to find the exact location of the payload once the balloon bursts and falls to the ground, it is necessary to transmit the location in some manner. The best way found was incorporating a system that using the telephone network able to transmit via SMS the location. Although there were many choices, the module acquired was the SIM 900 which despite being one of the cheapest it provides an external antenna that will ensure the continued service of the system.

5.2.6 HD Camera

In spite of the main purpose of the experiment being the recollection of data, one of the ideas proposed that finally came into being was the integration of an HD sports camera to record the whole trajectory and be able to perform a visual study of the stratosphere.

The selection of the camera was made taking into account the low temperature conditions present in the stratosphere at such high altitudes since the lens will be continuously exposed to the outside. Thus justifying the use of a sports camera that is prepared to experience extreme temperature and other hazardous conditions.

5.2.7 Power supply

The system will be powered by a set of AA batteries attached to the Arduino board since they were the cheapest and most simple option to provide the required 5V for the board.

5.2.8 Casing

As aforementioned, in the stratosphere the temperature is quite low, hence in order for the electronics to survive such endeavour, a Styrofoam casing will be used because of its isolating properties and its resistance to impact in case the landing system fails.

5.2.9 Lifting Gas

The gas chosen to be used is helium, due to its small price and ease of acquisition since there are many suppliers in the area of Madrid.

Chapter 6

Future Work

Once the project completed, both the theoretical and experimental part, it is time to define how this project can influence future applications and what could be improved or advanced in direct relation with the work exposed.

The first point to discuss is the further development of the simulator, the balloon model used could be perfected by a adding a complex thermal model to describe the temperature inside the balloon and the heat flow from the outside to the inside. By adding this extra influence, the temperature of the balloon plays a noticeable role on the volume expansion as the balloon rises to the stratosphere, hence changing the ascension profile making it closer to the experimental data.

Although the validation of the data was attempted, due to lacking precise wind data it was impossible to validate the simulator except for the altitude, so the next step would be finding experimental data to compare with the model. An experiment will be performed on the first week of July and then, accurate experimental data will be acquired and compared using the forecast data coming from the previous day.

The near-future continuation of the problem will be as aforementioned performed on the first week of July and the experimental set-up described in the document will be put to test following the proper regulations and legal procedures.

Using a more accurate wind forecast would allow for a better simulator since the ones from NOAA carry a big uncertainty and data regarding some days are absent from the database.

Revisit the legislation adapting the conditions for heavy category balloons or even powered ones.

Since the validation of the control system was completely impossible since finding experimental data of a controlled balloon proved unfruitful. Performing an experiment with a control system would be the best way to validate the model and study in real-time different possible applications.

Also, the optimization problem of the control system could be implemented in the future, by optimizing the power consumption of a set of compressors or reduce the overall weight by reducing the ballast required.

Adding lateral control to the simulator would be the next reasonable step once the altitude control is established. Although balloons can be operated in the stratosphere accurately, for other layers of the atmosphere, the balloons are really wind dependant. By adding a lateral control system it would be possible to perform manoeuvres in every layer of the atmosphere and have more accurate position and trajectory control.

Further work can be developed by proposing the application of the simulator on real missions. Two of which being the application of Google's Loon idea for increasing reception and internet speeds in the summer period in different areas of Spain that increase drastically in number of people due to tourism. The implementation of a controlled balloon in coast areas or islands during the 3-month period of summer would prove productive and a viable project proposal.

The second idea would be the one mentioned in state of the art, using the balloons as a surveillance method over different areas in risk of fire during summer. Such project can save a large amount of money by reducing the time since the fire starts until the fire-fighters reach the area and put down the fire.

CHAPTER 7

CONCLUSIONS

- Balloons play an important role in space investigation, weather forecasting and other fields proving their current importance and the necessity of a proper simulator to be able to predict the trajectory before launching.

- Uncertainty is an intrinsic part of weather forecasting, neglecting it leads to a solution far from the results extracted from experimental data. When taking this uncertainty into account it is possible to reduce the error and define a set of boundaries between which the solution will resemble the real data.

- With the proper optimization, most missions could reduce costs greatly by minimizing the displacements for payload recovery in the case of sounding balloons, optimizing trajectories to find the appropriate launching spot or reducing the power required to operate the balloon in problems with control system.

- The optimization system, helps ensure the fulfilment of the law by avoiding any kind of hazard to anyone since the landing position can be limited to a specific area. Selecting in advance a large enough zone, the launching position can be obtained. Contrasting such data with the air routes it is possible to ensure the complete safe flight of the balloon. This procedure was performed in order to apply it for the experimental launch intended to be launched on July.

APPENDIX A

GOBIERNO DE ESPAÑA MINISTERIO DE FOMENTO ENAIRE

SOLICITUD DE ACTIVIDAD AÉREA CIVIL RELATIVA A OTROS USOS DEL ESPACIO AÉREO

* A RELLENAR POR EL SOLICITANTE
** A RELLENAR POR EL COP

FECHA*			
REFERENCIA DEL SOLICITANTE*			
REFERENCIA ANTERIOR*		**REFERENCIA ENAIRE****	

1. Solicitante.

Nombre: ....

Dirección: ....

Teléfono: ....

Móvil: ....

Correo Electrónico: ....

2. Naturaleza de la actividad.

- ☐ Láser / Focos.
- ☐ Fuegos Artificiales.
- ☐ Suelta de Farolillos.
- ☐ Suelta de Globos
- ☐ Sondeos Meteorológicos.
- ☐ Globos Cautivos.
  - ☐ Publicidad.
  - ☐ Pasajeros.
  - ☐ Fotografía y Filmación.
- ☐ Área Segregada Temporal.
  - ☐ Publicada en el AIP (identificación y nombre): ....
  - ☐ Por Motivos de Seguridad para Acontecimiento Público o Privado: ....
- ☐ Otros: ....

3. Declaración de Autorización.

Por la presente designo y autorizo a ....
a actuar como representante en la tramitación de este formulario de solicitud de permiso, y coordinador de la actividad aeronáutica a realizar, pudiendo aportar, si se requiere, la información suplementaria necesaria.

Firma del Organizador

4. Fechas de la Actividad.

Fechas: ....

Horarios (Indicar si es Hora Local o UTC): ....

Duración de la Actividad: ....

5. Zona de Trabajo y Características de la Actividad (sistema de referencia WGS-84. Coordenadas geográficas).

Municipio y Provincia: ....

A. Tipo de Zona (en grados, minutos y segundos. Indicar longitud este u oeste. Añadir tantos puntos como sea necesario).

☐ Área circular / ☐ Punto / ☐ Polígono / ☐ Trayectoria.

Latitud	....	Longitud	....	☐ W/☐ E	Latitud	....	Longitud	.... ☐ W/☐ E
Latitud	....	Longitud	....	☐ W/☐ E	Latitud	....	Longitud	.... ☐ W/☐ E
Latitud	....	Longitud	....	☐ W/☐ E	Latitud	....	Longitud	.... ☐ W/☐ E
Latitud	....	Longitud	....	☐ W/☐ E	Latitud	....	Longitud	.... ☐ W/☐ E
Latitud	....	Longitud	....	☐ W/☐ E	Latitud	....	Longitud	.... ☐ W/☐ E
Radio	....	☐ Nm / ☐ Km / ☐ m						

B. Altura sobre el Terreno (AGL) o Altitud sobre el Nivel del Mar (AMSL).

Indicar unidad y tipo: .... ☐ ft ☐ m / ☐ AGL ☐ AMSL

C. Otros Datos: ....

6. Características de la Actividad (información adicional para las siguientes actividades).

☐ **A. Sondeos Meteorológicos.**

Tipo de sondeo: ☐ Ligero / ☐ Medio / ☐ Pesado.

Diámetro máximo del globo: .... m
Color del globo: ....
Régimen de ascenso: .... m/sg

Peso de la sonda / globo: ..... / ..... Kg
Número de globos: ....
Régimen de descenso: .... m/sg

☐ **B. Suelta de Farolillos / Suelta de Globos.**

Número de globos: .... Diámetro: .... Color: ....

☐ **C. Láser / Foco.**

Barrido horizontal del haz (Entre 0º y 360º): ....

Barrido vertical del haz (Entre la horizontal 0º y 90º): ....

☐ **D. Otros Datos:** ....

7. Declaración de Conformidad.

Declaro que:

1. La información contenida en este formulario, así como la documentación adjunta, es real, verdadera y correcta.
2. Cuento con la habilitación necesaria para poder acometer la actividad solicitada.
3. El personal y/o medios materiales empleados para realizar la actividad cumple con la normativa vigente así como con los requisitos establecidos por la DGAC (Dirección General de Aviación Civil) / AESA (Agencia Estatal de Seguridad Aérea).

Firma

Remitir a:
ENAIRE
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